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Westside RMZs and the DFC Model: Their Conceptual and Methodological Development

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Westside RMZs and the DFC Model: Documentation Of Their Conceptual and Methodological Development

Prepared for

RSAG – the Riparian Scientific Advisory Group, and
CMER – the Cooperative Monitoring, Evaluation, and Research Committee

Olympia, Washington

By

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Mason, Bruce, & Girard, Inc.
Portland, Oregon

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Executive Summary

This report presents the results of a study intended to document the data, assumptions, and rationale behind the development of the riparian management zone (RMZ) rules and the DFC model used in the state of Washington on state and private lands. Research for the study was done by interviewing several participants in the process, and by reviewing white papers, memos, meeting handouts, and emails generated during the process of developing the rules and model.

Results of the study answered questions posed by RSAG – the Riparian Scientific Advisory Group, and CMER – the Cooperative Monitoring, Evaluation, and Research committee. Major findings included the following:

- The rationale behind the adoption of three different zones for the riparian buffer was a result of compromise among caucuses; it was a negotiated solution featuring a mix of science and politics. The core zone is important for shade/temperature, bank stabilization, sediment filtration, and recruitment of large woody debris (LWD) and leaf litter. The inner zone provides LWD, and the outer zone completes a buffer equal in width to site potential tree height (SPTH).
- The basis for setting the width of RMZs, and varying the zone widths by site class, stream size, and management option, was largely attributed to satisfying caucus goals for the recruitment of LWD; the final widths were certainly a result of negotiation and compromise.
- The protocol used to establish the basal area targets at age 140 relied on a derived ratio of riparian basal area to upland basal area of about 81%. This was assumed to be constant over site classes, and was based on a *predicted* riparian basal area (through regression analysis) at age 140 and an *estimated* average site index of 150.
- Although some participants regard the minimum residual of 57 trees per acre in the inner zone to have been a negotiated figure, the number is not without technical merit. Work by Welty showed this number of trees to be capable of meeting the LWD recruitment requirements, and accounted for windthrow after thinning occurred. In his analysis, thinning occurred at age 50.
- The DFC Model does a good job of replicating projections by the SMC variant of ORGANON. There are some recognized problems pertaining to hardwood growth that should be addressed in the DFC Model. Selection of ORGANON as the underlying growth model appears to have been a rational choice, recognizing that any growth model offers pros and cons.

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Introduction

New forest practice rules governing silvicultural activities in riparian management zones (RMZs) on state and private lands in Washington will go into effect in 2001. These rules, largely based on the Forests and Fish report, are the results of years of negotiation between numerous stakeholders. The rules are intended to provide compliance with the Endangered Species Act for riparian and aquatic species, meet Clean Water Act requirements for water quality, restore and maintain riparian habitat to support a harvestable supply of fish, and keep the timber industry in the State of Washington economically viable (WSR 2001; page 138.)

This report provides the results of a study to document the rationale behind the RMZ rules for type 1, 2, and 3 streams in western Washington[1], and the assumptions and methodology behind the development of the DFC (Desired Future Condition) Model, a computer program designed to help forest managers determine allowable silviculture in the RMZ, and in fact required by the Washington DNR for completing forest practice applications in RMZs. At the outset of the study it was expected that the rationale would include a combination of science-based observations, professional judgement, and political compromises, and as such would provide a good companion report to an earlier, more extensive study of the scientific foundations of the Forests and Fish plan (CH2Mhill 2000).

Objectives

The general objective of the study was to document in one report the rationale behind the RMZ forest management rules, and the methods and assumptions used to develop the DFC Model. Specific goals of the project were to document:

1. The rationale for creating RMZs and for setting attribute targets by which the width of core, inner and outer zones vary (these include site potential tree height (SPTH), site class, stream width, and management option);
2. The data source(s) and calculations used, and assumptions made, to set basal area targets at stand age 140, and minimum residual trees per acre targets; and
3. The assumptions made and the methodology used to develop the DFC model and program its quantitative outputs.

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[1] The DFC model and the rules discussed in this report are specific to the forestlands in the state west of the Cascade Mountains. East of the Cascade crest, riparian strategies recommended in the FFR and subsequently adopted into forest practices rules were influenced by climatic and forest conditions that are different from the Westside.

Methods

This report is basically the result of a research study conducted in late May and early June of 2001. Numerous participants in the development of the RMZ rules and DFC Model were contacted by phone or email, told about the study, and asked if they were willing to participate by providing oral or written comments or documentation in line with the goals of the project. Comments were received in a combination of phone interviews, emails, voice mails, faxes, and a face to face interview. In all 11 different people were interviewed for the project. Notes from the interviews were captured in an Access database, and each interview received a unique interview number. The names of all interviewees are listed under "List of Interviews".

Any relevant documentation that could be obtained in the given time frame was also reviewed. Documents included journal publications, unpublished papers, government publications, meeting handouts, handwritten notes from meetings, email, and computer code. All documents were recorded in an Access database and assigned a unique document number. All documents used in the study are shown under "List of Documents".

In this report any references to information gained through interviews will include the person's last name and interview number. References to documents will include the author's name and date, or name and document number.

Results

Organization

The Results are organized according to the directions in the NWIFC Statement of Work. There are five sections, each beginning with the section description as written in the Statement of Work.

1) The rationale used to manage riparian areas in three different zones, each with differing management objectives and permissible activities.

The RMZ rules for western Washington fish-bearing streams (Type S and F waters) require a three-zone buffer (WSR 2001, p. 139-140). The zones are generally described as the *core zone*, next to the stream, a 50-foot wide "no-touch"[2] area; an *inner zone*, an area between 50 and 80 to 150 feet from the stream with restricted management activity; and the *outer zone*, extending from the outer edge of the inner zone to a distance equal to one site potential tree height (SPTH) from the bankfull width or channel migration zone, whichever is greater (Mitchell 2000; Goos 2000). The outer zone may be managed, but 10 to 20 riparian trees per acre must be left in the zone, depending on other management

[2] The term "no-touch" was used during FFR discussions to represent the zone where no timber harvest would be allowed. The rules allow for some road crossings and cable yarding corridors to pass through the core zone.

or management restrictions in the stream channel, core, or inner zone. All distances are horizontal from the stream.

The establishment of three zones was described by CH2MHill (2000, p. 1-3) as a "riparian strategy", but it might be alternatively described as the result of a series of negotiations and compromises involving several stakeholders, or "caucuses" in the language of the Forests and Fish Report. In the winter of 1997-98, each caucus was asked to develop a "credible proposal" (Heide, I15) regarding how to approach the management of RMZs. These were summarized by Kate Sullivan (Heide, I15) in her role as co-chair of the Science Team[3]. Some common themes emerged from this initiative. One was that of a no-touch zone; although there were differences of opinion regarding how wide it should be, there was agreement that a zone was needed adjacent to the stream to protect bank stability, filter sediments, provide shade, and recruit leaf litter and large woody debris (LWD) (Heide I15; Boyd I6; Pavel I11; Beechie I12). Boyd (I6) mentioned that the core zone also was in line with requirements of the Clean Water Act, and that a no-touch zone was one of the main requirements of the federal agencies. Hunter (I7) described the core zone as an unconditional requirement of the EPA and Washington Department of Ecology.

The establishment of the two additional zones (inner and outer) can be described as the result of compromises between caucuses. There was general agreement that more buffer (in addition to the core zone) was needed to recruit LWD into the stream. Environmental groups cited the FEMAT recommendation of a buffer equal in width to SPTH, and the NMFS considered the SPTH buffer to be non-negotiable (Hunter I7). The tribes were lobbying for, in fact, a 100' no-cut buffer (Heide I15), with a major goal being the recruitment of 85% of the potential amount of LWD (Hunter I7; Bilby I8; Beechie I12; Pavel I11). At the same time, the industry caucus was concerned about restrictions on harvesting in a full SPTH buffer (Boyd I6), and argued that trees farther from the stream were less likely to contribute LWD.

Eventually a compromise was reached based on the understanding that the *effective* distance from the stream for recruitment of LWD was in fact *less* than a full SPTH. This was based on the realization that (1) LWD had to be larger than a certain size [in terms of upper stem diameter, approximately 6" (Pavel, I11)[4]] to be useful in the stream[5], and (2) trees standing a full SPTH from the stream had very little chance of contributing LWD. The compromise resulted in the two additional zones; together they would provide a full SPTH buffer, but the inner zone, where management would be restricted, would only be 2/3 to 3/4 of the SPTH.

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[3] The Science Team was co-chaired by Joseph Pavel (NWIFC) and Kate Sullivan (Weyerhaeuser Company). The charge of the Science Team was to define resource questions to be addressed in Forests and Fish negotiations (Pavel I11), and to develop the best scientific approach to establishing riparian buffer regulations (Hunter I7).

[4] LWD is generally considered to be "functional" when above some minimal size, dependent on the stream size and energy; a large stream requires larger LWD than a small stream. See Bilby and Ward (1989) and Beechie and Sibley (1997) for supporting data and analyses.

[5] "Effective tree height" refers to the height at which the minimum tree diameter will be encountered to make the LWD functional (Bilby, I8).

The existence of the outer zone may be considered to be almost an artifact, in that it simply helped to fulfill the desire, on the part of some caucuses, to get a full SPTH buffer (Hunter I7). The 10 to 20-residual tree minimum for the outer zone was seen as largely unimportant by the tribes (Beechie I12), with little numerical justification (Hunter I7). The purpose of the outer zone is described as wildlife habitat (Boyd I6), and to protect special sites such as seeps, springs, or forested wetlands (Goos 2000). Residual trees in the outer zone may be clumped to protect these features (FFR 1999, p. 21).

To summarize, the rationale behind the adoption of three different zones was a result of compromise among caucuses; it was a negotiated solution featuring a mix of science and politics. The core zone was important for shade/temperature, bank stabilization, sediment filtration, and recruitment of LWD and leaf litter. The inner zone provides LWD, and the outer zone completes a buffer equal in width to SPTH.

2) The basis for setting the width of RMZs, and varying the overall width of each zone by site class, stream size, and management option.

The following table summarizes RMZ widths as a function of stream size, site class, and management option. All values are from the Forest Practices Board Manual (DNR 2000, pages M85-M87) for west-side streams. The zone widths under management option 2 do not vary formulaically but rather are negotiated widths. This is in contrast to management option 1 where widths are set at either 2/3 or 3/4 SPTH.

Management Option 1 – Thinning from below in inner zone.

Site Class	RMZ Width or SPTH[6] (feet)	Core Zone Width (feet)	Inner Zone Width (from outer edge of Core Zone) (feet)		Outer Zone Width (from outer edge of inner zone)	
			Stream Width ≤ 10' (to 2/3 SPTH)	Stream Width > 10' (to 3/4 SPTH)	Stream ≤ 10'	Stream > 10'
I	200	50	83	100	67	50
II	170	50	63	78	57	42
III	140	50	43	55	47	35
IV	110	50	23	33	37	27
V	90	50	10	18	30	22

Management Option 2 – Leaving trees closest to water in inner zone.

			Width from outer edge of core	Minimum floor (from core)	Width from outer edge of core	Minimum floor (from core)		
I	200	50	84	30	84	50	66	66
II	170	50	64	30	70	50	56	50
III	140	50	44	30	n/a	n/a	46	n/a

[6] These SPTH values correspond to the average total height of dominant and codominant trees at 100 years of age in Bulletin 201, Table 1 (McArdle and Meyer, 1949; page 12).

Management Option 1 allows for thinning from below throughout the inner zone, without decreasing the proportion of conifer species in the stand, and leaving at least 57 trees per acre, as long as it can be shown that the Desired Future Condition (DFC) basal area target will be met. The objective of thinning is to shorten the time required to meet LWD fish habitat and water quality needs by accelerating the growth of large residual trees (DNR 2000, page M85).

Management Option 2 allows for harvesting that will leave trees closest to the water, i.e., closest to the core zone. The rationale is to achieve DFC in a position as close to the stream as possible. Harvest is not allowed in the "floor", i.e., within 30' of the core for small streams, and within 50' of the core for large streams. Trees are selected for harvest starting from the outer most portion of the inner zone first, and then progressing toward the stream. A minimum of 20 riparian leave trees per acre will be retained in the harvested portion of the inner zone[7](DNR 2000, page M-86, 87).

Interviews and documents reviewed for this project make it clear that setting the overall width of the RMZ to a distance equal to SPTH was the subject of much debate among the caucuses (Hunter I3; Burcham 1998, H6). Reference to the idea of using SPTH to define the buffer width is seen as early as August, 1998 (Unknown 1998, H5), and was a recurring theme in subsequent meetings that year (Unknown 1998, H7; Bilby 1998, W13; WFPA 1998, H12). Adopting a buffer width equal to SPTH was a primary goal for USFWS and NMFS (Boyd, I6; Hunter I7). The tribes wanted a buffer of sufficient width to recruit 85% of the potential LWD (Bilby, I8; Pavel, I11); the amount of LWD that could be recruited by buffers of various widths was the subject of several analyses (e.g., Bilby 1999, W12) and appeared to be a driving factor in the adoption of SPTH. There was some argument about the appropriateness of using Douglas-fir as the index species, and about defining SPTH at 100 years of age (Pavel, I11); some parties felt the SPTH should be defined as the asymptotic height in each site class, roughly occurring between 150 and 200 years of age (Beechie, I12)[8].

Varying zone width by stream width was a contentious issue (Hunter I7). He felt that compromising on a smaller buffer for smaller streams was justifiable because smaller streams would not flush away LWD as fast as larger streams, and the size of LWD needed to meet functional requirements is smaller on small streams; the result is that LWD recovery time is substantially shorter on small streams. Beechie (I12) remarked that although there was nothing in the scientific literature drawing a distinction between streams less than or greater than 10 feet in width, the distinction (in the rules) probably came to be due to industry's concerns about the large number of small channels on timberland. Industry's position was that less wood was needed in small streams, so a smaller buffer was justified (Beechie, I12).

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[7] There seems to be some confusion in the Forest Practices Board Manual (DNR 2000, page M-86) on this point. Item 2.D. on that page mentions both a 20 tpa minimum and 10 tree minimum.

[8] A close look at the height curves in Bulletin 201 (McArdle and Meyer 1949; page 13) suggests the age at which the heights are asymptotic may be 300 years or older.

Heide (I15) described the 2/3 and 3/4 values for defining the inner zone as "eventually negotiated" values. Since the primary purpose of the inner zone was for recruitment of LWD, the merit in basing the width of the inner zone on a fractional tree height was that trees any farther from the stream would have very little chance of falling into the water (Boyd, I6).

The choice of management option does not affect the overall RMZ width, but the selection of management option 2 does effectively narrow the inner zone for site classes I and II on larger streams. As mentioned previously, the rationale for the change in width is that management option 2 also results in a 100' no touch zone, comprised of the 50' core and an additional 50' of the inner zone. This puts the source of LWD closer to the stream. [Although management option 2 may at first appear to be the more attractive of the two alternatives on industry land, Heide (1999, M2) felt there may be a preference for the thinning option, which would lead to long term maintenance of wider buffers, particularly on smaller streams.]

The Forest Practices Board Manual (DNR 2000, p. M-99) also allows extra trees to be removed from the outer zone in exchange for the placement of LWD in the channel (Hunter 1998, W18), but this provision does not affect zone width.

In summary, the basis for setting the width of RMZs, and varying the zone widths by site class, stream size, and management option, was largely attributed to satisfying caucus goals for the recruitment of LWD; the final widths were certainly a result of negotiation and compromise.

3) The protocol used to develop basal area targets, including a description of the type and quality of data used, assumptions made in extrapolating these data, and calculations made.

The Desired Future Condition (DFC) of the RMZ is defined in terms of a target basal area per acre for the combined core and inner zone at age 140 for the given site class. These targets are listed in DNR (2000, p. M-85):

Table 3.1

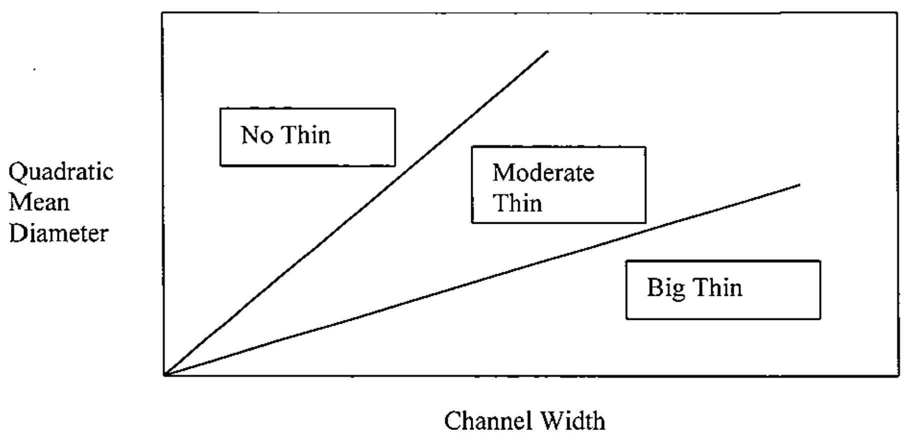
Site Class	DFC Target BA/a (Sq. Ft. at 140 yrs.)	Bulletin 201 BA/a at 140 yrs[9]
I	285	350
II	275	338
III	258	317
IV	224	275
V	190	238

[9] BA/acre figures shown for reference only; page 15, McArdle and Meyer (1961).

The caucuses considered at least three other approaches to regulating management in RMZs before reaching consensus on the DFC BA/a approach (Hunter, I3; Boyd, I6; Bilby, I8; Pavel, I11.) Early approaches were oriented to management activities in the channel (the "engineered approach", favored by industry (Beechie, I12)), as opposed to management of the riparian buffer. Previously published articles in the scientific literature (e.g., Beechie and Sibley, 1997; Bilby and Ward, 1989) provided some guidelines that related pool formation to channel size and the size of LWD, and the characteristics of LWD resident in channels of various sizes, but the engineered approach was eventually dropped by the caucuses. It was described as too technical and experimental by some caucuses (Boyd, I6), and others felt that moving away from the engineered approach "eliminated some simplifying assumptions" (Bilby, I8), which presumably made some caucuses uncomfortable.

Attention then turned to managing the riparian buffer. For example, a handout titled "Five-Caucus Proposal – August 20, 1998" (Unknown 1998, H5) provided a thinning chart (reproduced here) to use as a guide for management in the inner zone. The same handout refers to "pool forming wood" and "key piece size" in conjunction with using the thinning chart.[10]

THINNING CHART (8/20/98)



Attention eventually shifted from *how to treat* the buffer to *what the buffer should look like,* largely due to a lack of agreement among caucuses as to the actual silvicultural activities that should be prescribed or allowed in the inner zone (Heide I15).

A "dual-target" concept was considered for defining what the buffer should look like. The idea was to meet both density (trees per acre) and basal area targets, recognizing that a stand of small trees and a stand of large trees, both with the same basal area, were not contributing the same benefits in terms of riparian function (Beechie, I12). A meeting of

[10] The idea of determining the types of siliviculture to be allowed in the inner zone was evidently still a topic of discussion a year later. Beechie (1999, H14) presented a "thinning graph", similar in form to the thinning chart shown here, but prescribing different relative densities to thin to as a function of qmd and channel width.

the Desired Future Condition and Pathways Workgroup in October 1998 noted an area of agreement among caucuses as "the desired future condition (DFC) will be determined by the basal area (ft^2 per acre/1,000 ft.) and tree density (trees per acre/1,000 ft.) at age 140" (Unknown 1998, H8)[11]. A handout at that meeting (Bilby 1998, W13) featured suggested BA and density targets as a function of site class.

Eventually the simpler concept of target basal areas was agreed to. Target basal areas at age 100 had been proposed in September of 1998 by the NMFS (Unknown 1998, H7) as shown in Table 3.2, and Bilby (1998, W13) had used an age of 50 years for his BA targets.

The Forests and Fish Rules that were eventually adopted specified DFC at age 140, which begs the question of how the target *age* was arrived at. The 140 year specification appears to have been adopted by November of 1998 (Burcham 1998, H6), if not earlier. The age of 140 years appears to have simply been the midpoint in the interval of 80 to 200 years, which was considered to be old enough to provide the shade and LWD recruitment required by the caucuses (Hunter, I7); Pavel (I11) described 140 years as a compromise among caucuses.

Table 3.2 Proposed target BA/a at age 100 (Sept. 98)[12].

Site Class	BA/acre
I	247
II	239
III	224
IV	194
V	168

The caucuses were faced with the problem of establishing average BA/acre values at age 140, by site class, in riparian areas. They had Bulletin 201, which provided average BA/acre by site class and age for upland areas, but lacked similar data for riparian stands. The strategy became one of scaling the Bulletin 201 BA/site relationships down to reflect expected BA/a figures at age 140 in riparian stands. Parton (1998, W9) had a key role in promoting and facilitating this concept; excerpts from his October 19, 1998 draft proposal are illuminating[13]:

[11] The units of basal area and trees per acre *per 1,000 feet* may have been unintended, but that is how they were reported in H8. I do not know what the units were intended to be at that time.
[12] Parton showed that these values were approximately 80% of the Bulletin 201 values. This can be verified by referring to Table 2 of McArdle and Meyer (1961), page 15, using the midpoints of the site classes at age 100.
[13] The entire proposal, which contained specifications on basal area, density, and average tree size, was not adopted (Boyd, I10), but the idea of using a ratio to establish riparian target BA figures was agreed to.

" Properly functioning riparian areas are not the same as fully-stocked (upland) stands. The few published, unpublished, and in press investigations of riparian forest ecosystems demonstrate marked differences in stocking, basal area, and community composition compared with upland forests....Combined with disturbance events, mature riparian forests are spatially diverse and understocked compared with upland stands managed for high yield ....Riparian tree growth has not been described in yield tables like those available for upland stands. We propose a method to adapt upland stand tree density and sizes at DFC ages to represent properly functioning riparian conditions based on published, in press, and unpublished data from more than 100 riparian stands in western Washington and northwest coastal Oregon."

WFPA contracted a study by the University of Washington to determine average basal area per acre values on riparian sites (Moffett et al, 1998,W17). That study and the ensuing analysis to develop a ratio to determine riparian basal areas at age 140 by site class were described by Schuett-Hames et al (2000, W8):

"The process of establishing the current desired future condition performance targets for western Washington had two steps, the first being the analysis of existing data and the second being an extrapolation of that data to come up with the existing basal area by site class targets. A team from the University of Washington compiled and analyzed stand data from three different sources; Forest Inventory and Analysis (FIA) plots, Mount Baker Snoqualmie and Olympic National Forest Service plots, and timber industry plots (Moffet et al., 1998). FIA data were used if the stand was >80 years of age and within 65m of a Class 2 stream, Forest Service data were screened to be >80 years of age and within 70m of a stream, and industry data were obtained from older structure stands adjacent to a stream. Aggregating all data sets, a total of 139 plots, the mean basal area for conifer dominated stands was 277 ft^2 /acre with a standard deviation of 128 ft^2 /acre, and a range from 30 to 712 ft^2 /acre. When these data were regressed against stand age they yielded an R^2 of 0.19.

To fit the structure of the riparian prescriptions (which are based on site class), additional analysis was conducted by a technical team (the Forests and Fish DFC work group) to develop basal area DFC targets by site class. First, a ratio was created of the riparian basal area by age (using the above mentioned regression) to upland stand basal area by age (McArdle et al., 1961) at a site index of 100[14]. Second, values for riparian basal area by site class were established by scaling the upland values from McArdle et al. by the ratio of riparian to upland basal areas at 140 years. This process yielded the basal area values for Site Class I-V of 285, 275, 258, 224, and 194 ft^2 /acre respectively. These values were incorporated as the DFC targets in the Forests and Fish Report and the Emergency Rules, with the exception of Site Class V which was adjusted to 190 ft^2 /acre."

The regression cited by Schuett-Hames et al was

$$BA/acre = 142 + 0.88(Age) \qquad \text{(Equation 3.1)}$$

as specified in Parton (1998, H3). Parton assumed the riparian plot data used by Moffett et al represented an average site index of 150[15], and generated the following table of ratios (Table 3.3):

[14] Actually, Parton's spreadsheet of 9/3/98 (H3) indicates a site index of 150 was used for this purpose.
[15] Parton (1998, H3) described the selection of SI 150 to represent the average SI for riparian areas in western Washington as "based on limited polling of knowledgeable professionals".

Table 3.3 Establishment of ratio to normal stocking by Parton.

Age	Riparian BA/a from regression	BA/a at site index 150 from Bull. 201	Ratio of riparian BA to Bulletin 201 BA
80	212	266	.798
90	221	279	.793
100	230	291	.790
110	239	301	.793
120	248	310	.799
130	256	318	.806
140	265	326	**.813**
150	274	333	.823

The ratio of .813 was then multiplied by the Bulletin 201 values for BA/a acre at age 140 for each site class midpoint to arrive at the DFC targets that were published as tentative by WFPA (H12) in 1998, and are now part of the regulations (Table 3.1).

Alternative basal area per acre figures for mature to old riparian forests west of the Cascades were presented by Rot (1998, H9). On 21 sites in the Gifford Pinchot and Mt. Baker-Snoqualmie National Forests, and Mt. Rainier National Park, he recorded basal areas from 150 to over 400 square feet per acre in stands from less than 100 to over 700 years old. In the age group of approximately 140 years, basal area ranged from 250 to nearly 400 square feet per acre, "substantially higher" (Burcham 1998, H6) than the values arrived at using Parton's ratio approach.

Parton was adamant about doing follow-up work to validate the basal area targets that were eventually adopted (Hunter, I7). Validation work is well justified in that the protocol used to establish the basal area targets at age 140 relied on a *derived* ratio of riparian basal area to upland basal area of about 81%. The ratio was assumed to be constant over site classes, and was based on a *predicted* riparian basal area (through regression analysis) at age 140 and an *estimated* average site index of 150.

Follow-up work to validate target basal areas is also justified in order to clarify questions regarding species composition. According to Boyd (I6), the intention was to only include conifer species in the target basal areas, because conifers provide large woody debris to the stream that is more stable than that provided by hardwoods. The intention was to include all conifers, not just Douglas-fir. In contrast, the report by Moffett et al (1998, W17) implies that "conifer-dominant" plots were used for the basal area-age regression; the Washington Forest Practices Board defines a conifer-dominant area as one with as much as 30% hardwood (Unknown 1998, H10). In addition, Welty's recollection (I13) is that the original BA targets did include hardwood. [16] Dead trees were not intended to be counted toward satisfying the DFC goals, nor were they used in establishing the goals (Boyd I10; Welty I13).

To summarize, the protocol used to establish the basal area targets at age 140 relied on a derived ratio of riparian basal area to upland basal area of about 81%. This was assumed to be constant over site classes, and was based on a *predicted* riparian basal area (through regression analysis) at age 140 and an *estimated* average site index of 150.

4) The protocol used to establish minimum tree per acre requirements, including a description of the type and quality of data used, assumptions made in extrapolating these data, and calculations made.

The Forest Practices Board Manual (DNR 2000, W16, page M-85) specifies that the number of residual trees per acre in the inner zone will equal or exceed 57 trees per acre under the option of thinning from below (Management Option 1).

Bilby (I8) described the figure of 57 trees per acre as a negotiated number; the caucuses knew they had to have at least enough trees to achieve the BA targets at age 140, there was some debate that put the required number of leave trees in the range of 30 to 80[17], and 50 was taken as the average; 7 more were added to account for blowdown, which was assumed to occur within 1-3 years after harvest (Bilby, I8). Pavel (I11) also described the 57 figure as a compromise (median) value, and was of the opinion that leaving more stems would be appropriate. The tribes lobbied for more residual trees because the DFC target only specified basal area, not LWD, which was their primary concern; as a consequence the 57 tree rule is largely in response to the tribes quest to get 85% of the potential LWD (Hunter, I7). To the contrary, industry representatives felt that the goals could have been achieved with as few as 26 or 27 residual trees per acre (Boyd, I6).

Heide (1999, M2) described simulation work by Welty to predict LWD recruitment potential on small streams if the inner zone was thinned to 50 residual trees per acre. All thinning was done from below, and the proportion of conifer in the stand could not be reduced due to thinning. A 50-year harvest age was assumed, and the inner zone was assumed to be fixed at 2/3 of the SPTH. The results of the study showed that unless the stocking was low in the core zone, leaving 50 trees per acre at age 50 in the inner zone would result in at least 84% of the potential recruitment of LWD. Welty (2001, W11)

[16] In his review of the draft version of this report, Peter Heide noted that "in the negotiations it was agreed that maple and cottonwood (relatively long-lived hardwoods) would be included in the measure of BA used to evaluate whether or not a stand would meet the BA standard."

[17] One of the documents collected for this project is a 12-page handout with graphs showing percent of functional LWD recruited as a function of channel width, leave trees per acre in the inner zone, site index class, and conifer stocking. The date and author are unknown. The number of residual trees per acre ranges from 30 to 80.

described this work as "confirming that the potential recruitment of large woody debris was not limiting" if the residual trees per acre was as low as 50.

Welty (1999, W1)[18] conducted a technical analysis showing that on Site Class III, leaving 48.5 trees per acre (15" average dbh) at age 50 will result in crown closure by age 70, well before the target DFC age of 140. Given a windthrow rate of approximately 14% (attributed by Welty to Grizzel et al), the number of residual trees per acre was increased to 56.5. It was assumed that there would be zero mortality due to suppression and age in a 50 year old stand with only 57 trees per acre (Welty, I16).

In summary, the 57 trees per acre figure was a negotiated guideline, supported with some technical analyses that showed LWD recruitment requirements would be satisfied, and the site would be fully occupied.

5) The methodology used to develop and program the DFC model including a description of modeling assumptions.

The Forest Practices Board Manual (DNR 2000, W16, page M-85) specifies that no thinning may occur in the inner zone unless it can be shown that the DFC target basal area at age 140 will be achieved by the combination of the core and inner zones. The DFC Model, a computer program that predicts the stand basal area per acre at age 140, is the tool to be used for conducting the test.

The DFC Model interface was designed by Mr. Wade Boyd of Longview Fibre Co., and the program coding and growth model adaptation work were by Mr. Jeffrey J. Welty, Biometric Support Engineer, Weyerhaeuser. An example of the basic worksheet for data entry to the model is shown in Figure 5.1. The user specifies site class, stand age, and major species for the stand, and then supplies basic inventory information consisting of the number of trees by dbh class. The model uses these data to predict the percentage of the DFC target basal area that will be achieved by age 140.

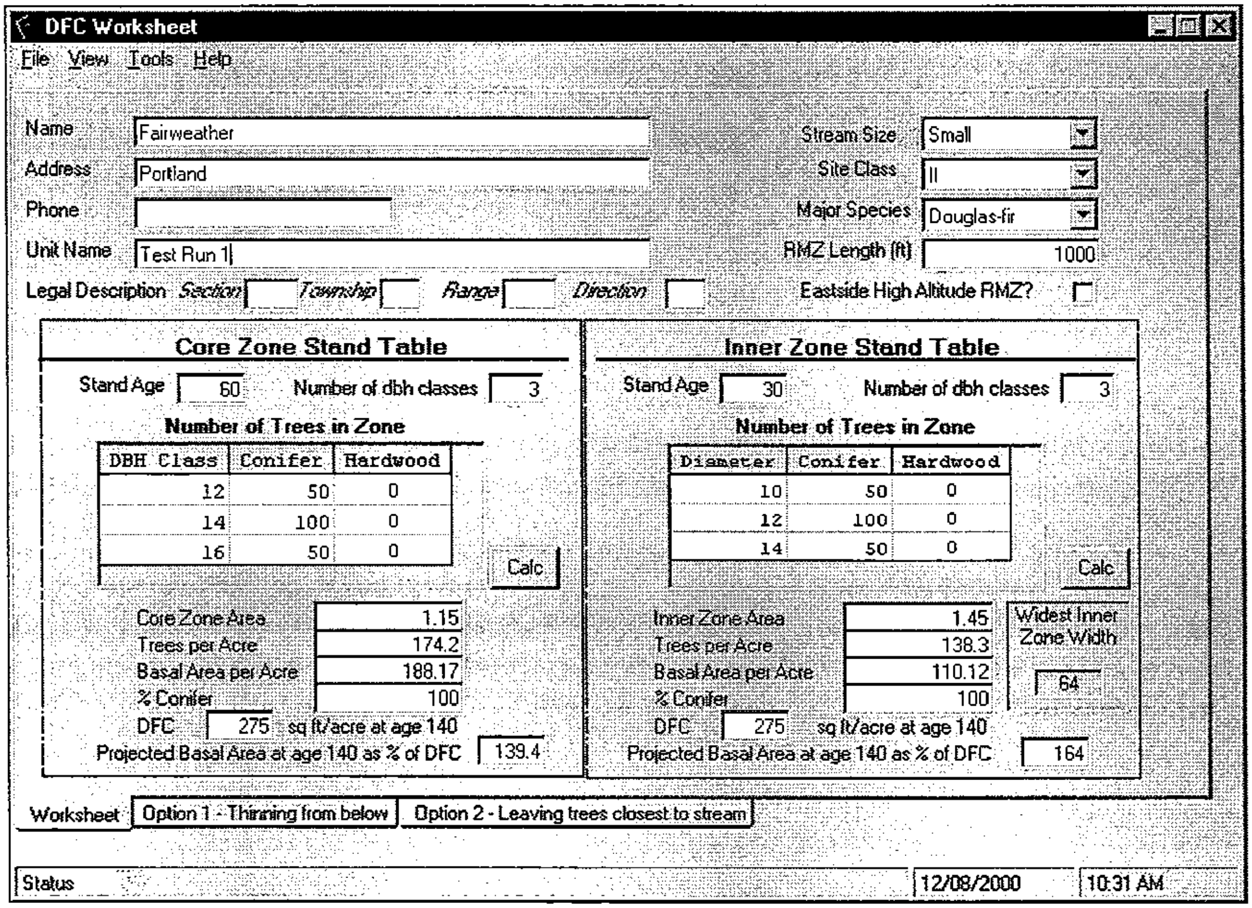
The DFC Model *reflects* projections made by the ORGANON (Hann et al, 1995) growth model, but it does not *run* ORGANON per se. Instead, the DFC Model makes use of the results of thousands of ORGANON simulations to predict the stand basal area at age 140. A similar idea was suggested by Harrison and Twark in 1991 (P1), who coined the term "pseudodata analysis" to describe the use of models (rather than empirical observation) to collect data.

The DFC Model actually makes use of many lookup tables which display the predicted basal area per acre at age 140 as a function of initial trees per acre, initial basal area per acre, initial age, site index class, and species composition (percent hardwood). The tables were created using SAS programs[19] developed by Welty. SAS was used to fit regressions

[18] Welty's technical analysis of the required minimum number of residual trees per acre is in Appendix A.
[19] FITNEW.SAS and DUMPPARM.SAS

to the results of ORGANON runs, and the regressions were used to create the lookup tables.[20]

Figure 5.1. Example of opening data entry screen for DFC Model.



The SMC (Stand Management Cooperative, University of Washington) variant of ORGANON was used to create the data sets eventually used to fit the regressions. A stand table (for input to ORGANON) was created for a range of trees per acre and basal area per acre combinations, for each site class/percent hardwood/total age category. A total of 7,560 stand tables (and ORGANON runs) were made, as shown in Table 5.1.

Table 5.1. Derivation of 7,560 Organon simulations to create regression data sets.

Category Descriptions	Cumulative Combinations
5 site index classes: I, II, III, IV, V	= 5
6 species comp (% hdwd) classes: 0, 10, 20, 30, 40, 50	x 6 = 30
6 total age classes: 35, 55, 75, 95, 115, 135	x 6 = 180
7 tpa classes: 50, 60, 100, 150, 200, 250, 300	x 7 = 1,260
6 ba classes: 50, 60, 100, 150, 200, 250	x 6 = 7,560

[20] Much of the information in this section was originally explained by Welty; see Appendix B.

A regression was fit to the 42 observations (7 tpa classes x 6 ba classes) in each site index/percent hardwood/total age category to predict a value referred to as "Min_tpa". This value was defined as the product of initial trees per acre and the ratio of the DFC target basal area per acre to the projected basal area per acre at age 140.[21] Welty used a model form that had been developed earlier in the Forests and Fish negotiations (Welty 2001, W11):

$$\text{Min\_tpa} = b_0 + a(\text{tpa}) + b(\text{tpa}/\text{ba}) + c(\text{ba}), \qquad \text{(Equation 5.1)}$$

where Min_tpa was actually defined as tpa x (DFC ba target)/(ba at 140).

This is an interesting model, because the same variable (tpa) appears on both sides of the equation. Welty experimented with other forms, but none were as good as this one (Welty I16). Using some algebra, the model can be used to derive both projected basal area at age 140, and the number of trees to thin to in order to reach the DFC target. The model makes practical sense in that if the ratio of the DFC basal area target to the basal area at age 140 is less than 1.0, the current tpa is evidently sufficient to meet the DFC target, and therefore can be reduced by thinning; the allowable amount of reduction (the thinning intensity) is equal to the ratio of the DFC target to the predicted basal area at 140.

An example will help to illustrate this idea. PARMDF2.DAT (Appendix C) is a file created by one of Welty's SAS programs. It contains the regression coefficients (b_0, a, b, and c) for each of 180 site/age/species composition combinations. The DFC worksheet in Figure 5.1 shows an estimate of 139.4% of the DFC target basal area at age 140 for the core zone; how did the DFC Model arrive at that number?

The DFC target basal area for a site class II is 275 square feet per acre. The initial ba and tpa values were 188.17 and 174.2, respectively. The species composition was 0% hardwood, and the stand in the core zone was 60 years old.

The coefficients in PARMDF2.DAT are available for stand ages of 55 and 75, but not 60, so interpolation will have to be used to derive the results at age 60[22]. At age 55, referring to equation 5.1 and using the correct coefficients from PARMDF2.DAT, the value of Min_tpa would be:

$$\text{Min\_tpa} = 13.67 + .7005(174.2) + 1.74(174.2/188.17) - .082(188.17) = 121.8832.$$

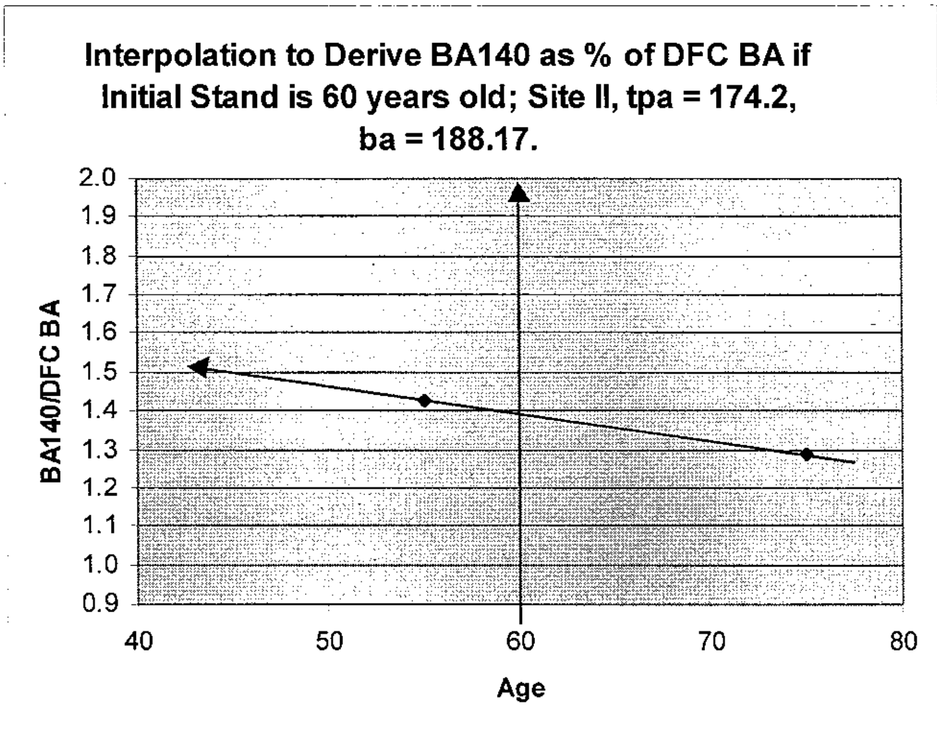
Since Min_tpa equals initial tpa times the ratio of DFC target to BA at 140 years,

$121.8832 = 174.2(275/BA_{140})$; with some algebra, $BA_{140} = 393.05$, which is 142.9% of the DFC target basal area at age 140.

[21] Recall that the regression data set would consist of initial tpa and ba, projected ba at age 140, and the DFC target ba, which would be a constant for the given site class.
[22] Welty mentions the use of linear interpolation and extrapolation in his documentation (Appendix B).

Going through the same calculations at age 75 yields a value for Min_tpa of 135.07, a value for BA_{140} of 354.6, and 128.9% of the DFC target basal area.
We can use a graphical approach to show that a value 139.4% at age 60 is a reasonable value (Figure 5.2).

Figure 5.2



As mentioned earlier, Welty had to create 7,560 stand tables as input to ORGANON. He described this process in good detail in Appendix 1 of his larger document (W2; Appendix B in this report). One of the key assumptions in that process was a coefficient of variation (CV) of 30% for the diameters in the stand, because it will determine the range of trees sizes around the average size. He conducted sensitivity tests (Welty 2001, E5), where he looked at the projected basal area at 140 years with initial CV values of 20%, 30%, and 40%. He found that the resulting BA_{140} values didn't vary by more than 5% from the BA_{140} when a CV of 30% was used, and concluded that 30% was a reasonable assumption (Welty, I13).

It would seem reasonable that the SMC variant of ORGANON could be used to verify the DFC Model's prediction of BA140 for a given site, age, and input tree list. In essence, this would be a test of the regressions, resulting lookup tables, and interpolation algorithms that the DFC model uses to arrive at the projected basal area. It would be unreasonable to expect an exact match, but the values should be close.

I conducted such a test by trying to replicate the results shown for the Inner Zone in Figure 5.1. The DFC model predicted that the basal area at age 140 would be 164% of the target basal area, which was 275 square feet per acre. Therefore the DFC model was predicting the basal area to be 451 square feet per acre at age 140. I used the SMC variant of ORGANON to project the same tree list, using the following input parameters: Doug-fir site index (age 50) of 124, breast height stand age of 23, and 7 years to breast height; all of the other input parameters were ORGANON defaults. The growth model predicted 433 square feet of basal area per acre at age 140, within less than 5% of the DFC model's prediction, suggesting that the DFC Model is doing a good job of emulating the ORGANON model.

Results from the DFC Model have also been evaluated by Martin (I2) at the request of Bernath (I14) when he was with the Washington DNR Forest Practices division. Martin met with Welty in Federal Way on October 27, 2000, and based on inspection of the model results (but not rigorous testing), determined that the modeling process was reasonable. Martin thought that some of the predicted basal areas at age 140 might be a little high, but were not unreasonable, especially when compared with yields in Bulletin 201 (McArdle and Meyer, 1961) (Martin, I2).

In earlier work (circa 1996) Welty originally used DFSIM for the modeling work. At the time his choices for growth models were DFSIM, FVS, and the DOS version of ORGANON; FVS was not widely used, and ORGANON was too difficult to work with, so DFSIM was the model of choice (Welty, I1).

He realized that DFSIM was less than ideal, in that it was designed to project even-aged Douglas-fir stands, and what was needed was projections of mixed-species stands that were not necessarily even-aged. Fortunately the ORGANON DLL became available, and it became an attractive alternative. Several regional biometricians and silviculturists participated in evaluating ORGANON as the model of choice (Hyink, I4; Oliver, I5; Marshall 2001, E8). FVS and FPS were also considered, but FVS was deemed unsuitable because there was a stochastic element to it, and default settings resulted in biologically infeasible stands; FPS was suggested, but was not used because there was no full peer review in the public domain (Welty 2001, W11). In spite of the fact that it lacked component models for red alder, the SMC variant of ORGANON was selected as the best alternative[23].

Welty has pointed out that modeling the hardwood component in the DFC Model is an area in need of improvement (Welty I13). First, the original ORGANON runs used coefficients for bigleaf maple to grow hardwoods, since red alder models were lacking. Second, an early assumption in the DFC modeling approach was that all hardwoods would be senesced by age 100; the problem is that the coding that triggers the senescence is not activated in the circumstance when an older stand (> 95 years) contains hardwood, so the model is flawed in the way it handles older riparian stands.

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[23] In the model runs, red alder was grown as bigleaf maple, which is represented in the SMC variant.

In summary, the DFC Model does a good job of replicating projections by the SMC variant of ORGANON, using a pseudo-data approach. There are some recognized problems pertaining to hardwood growth that should be addressed in the DFC Model. Selection of ORGANON as the underlying growth model appears to have been a rational choice, recognizing that any growth model offer pros and cons.

List of Documents

Document numbers (in parentheses) were assigned to each document. The following codes were used: E = email; W = white paper or technical report; H = handout at a committee or work group meeting; P = proceedings article; J = journal article; M = memo. All documents listed were reviewed and aided in compiling the report; an asterisk indicates the document is cited in the text of the report.

Beechie, T.J. 1999. (H14) Thinning graph for forest module. Meeting handout 10/21/1999. 1 page.

*Beechie, T.J. and T. H. Sibley. 1997. (J1) Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. Transactions of the American Fisheries Society, 126: 217-229.

Boyd, Wade. 2000. (H2) DFC ADGENDA [sic]. Meeting handout on 2/4/2000.

*Bilby, R.E. 1999(?). (W12) Buffer widths and wood delivery under the current riparian proposal. White paper, 10 pages.

*Bilby, R.E. 1998. (W13) Basal area and density targets based on data from Andrus (1998). Meeting handout 10/21/1998. 5 pages.

*Bilby, R.E. and J.W. Ward. 1989. (J2) Changes in characteristics and function of woody debris with increasing size of streams in western Washington. Transactions of the American Fisheries Society, 118:368-378.

*Burcham, J. 1998. (H6) Summary of DFC meeting at Point-No-Point, 11/6/98. Meeting minutes. 3 pages.

*CH2MHill. 2000. (W3) Review of the Scientific Foundations of the Forests and Fish Plan. Prepared for Washington Forest Protection Association. April 20, 2000.

DNR. 2001. (W10) Washington Forest Practices Board – Rule Adoption website. www.wa.gov/dnr/htdocs/fp/fpb/ruleadopter.html.

*DNR. 2000. (W16) Forest Practices Board Manual, March 2000. Section 7, Guidelines for Riparian Management Zones. Washington Dept. of Natural Resources, Olympia, WA.

*FFR. 1999. (W15) Forests and Fish Report, April 29, 1999. Appendix B and Schedule B-2. 204 pages. www.wa.gov/dnr/htdocs/fp/fpb/forests&fish.html.

*Goos, Ann. 2000. (W7) Implementation of the Forests and Fish Report – Progress to Date. Washington Forest Protection Association, August 29, 2000. 8 p.

Hann, D.W., A.S. Hester, and C.L. Olsen. 1995. ORGANON Users Manual. Oregon State University, Department of Forest Resources, Corvallis, OR. 127 p.

Harrison, T.P. and R.D. Twark. 1991. (P1) Determining forest management regimes via pseudodata analysis. In Proc., 1991 Systems Analysis in Forest Resources Symposium, Charleston, S.C., March 3-7, 1991. Page 46-53.

*Heide, Peter. 1999. (M2) Memo to Larry Waserman and Joseph Pavel Re: Discussion on Minimum Tree Count for Thinning Guidelines. 10/21/1999. 5 pages.

Heide, Peter. 1998. (M1) Memo to WFPA Forest Policy Committee Re: Status of Forestry Module TFW Negotiations. July 24, 1998.

*Hunter, Mark. 1998. (W18) Integrating riparian enhancement incentives into the forestry module. Issue paper 12/31/98. WDFW. 19 pages.

King, J.E. 1966. (W5) Site Index Curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Forestry Paper No. 8, July 1966. 49 p.

Marshall, David. 2001. (E8) RAIS Model. Email to Steve Fairweather 6/2/2001.

*McArdle, R.E. and W.H. Meyer. 1961. (W4) The Yield of Douglas Fir in the Pacific Northwest. USDA Technical Bulletin 201. 74 pages.

*Mitchell, C. 2000. (W14) Washington's Forests and Fish Agreement: New Forest Practice Rules. Forest Stewardship Notes, Volume 9, No. 2, Fall 2000. Washington State University.

*Moffett, J., M. Ludwig, and B. Lippke. 1998. (W17) Technical analysis for the Desired Future Condition Work Group – DRAFT. 10/28/98. University of Washington, under contract to WFPA. 8 pages + tables and figures.

Parton, Mike. 1998. (E7) New Buffer Width Pojections [sic]. Email from Parton to Joseph Pavel 11/13/1998.

*Parton, Mike. 1998. (H3) DFC Basal Area by Zone. Spreadsheet handout 9/3/1998. 2 pages.

*Parton, Mike. 1998. (W9) Draft Proposal – Riparian Pathways and DFC for Western Washington and Upper Elevation Forests of Eastern Washington. October 19, 1998. 12 pages.

*Rot, B. 1998. (H9) Cascade stand data, mature to old riparian forests. Meeting handout on 11/6/98 (revised 11/17/98). 3 pages.

*Schuett-Hames, D., M. McGowan, and D.R. Berg. 2000. (W8) Validation of Riparian Prescription Performance Targets. Briefing paper to NWIFC. June 2000. 18 p.

Unknown. 2000. (H1) Desired Future Condition Worksheet – Users Guide for Version 1.1.9. HTML document, Washington DNR website. 5 pages.

Unknown. 1999. (H13) DFC Meeting May 26, 1999. Summary notes. 1 page.

Unknown. 1998. (H11) Example computation – allowable harvest in inner zone. Meeting handout 11/16/1998. 3 pages.

Unknown. 1998. (H10) Desired Future Condition and Pathways Workgroup. Summary of meeting held 11/6/1998.

*Unknown. 1998. (H8) Desired Future Condition and Pathways Workgroup. Summary of meeting held 10/21/1998.

*Unknown. 1998. (H5) Five-Caucus Proposal – August 20, 1998. Meeting handout.

*Unknown. 1998. (H7) TFW Riparian Rule Notes (9/3/98). Meeting handout summary.

Welty, Jeff. 1999. (H4) Using the DFC Tables. Meeting handout 2/12/1999. 13 pages.

*Welty, Jeff. 1999. (W1) Forest and Fish Desired Future Condition Thinning Guidelines; Minimum Tree per Acre Analysis. White paper 10/22/99. 5 pages.

Welty, Jeff. 1999. (W2) Desired Future Conditions; Projecting Stand Conditions. White paper 10/29/99. 6 pages.

Welty, Jeff. 2001. (E1) Documentation of DFC Model. Email to Steve Fairweather 5/23/2001. 1 page.

*Welty, Jeff. 2001. (W11) History of DFC model development. White paper 6/5/2001. 1 page.

Welty, Jeff. 2001. (E6) DFC documentation; C source code and SAS jobs. Email to Steve Fairweather 6/6/2001. 1 page + attached zip file, DFC_FIT.ZIP.

Welty, Jeff. 2001. (E5) SAS listing of cv analysis. Email to Steve Fairweather 6/7/2001. 1 page + 2 attached files: CV_SENS.LST and CV_SENS.SAS.

*WFPA. 1998. (H12) Riparian package for fish-bearing streams, western Washington. Draft 3. Meeting handout 12/4/1998. 3 pages.

*WSR. 2001. (W6) Washington State Register, Issue 01-07, April 4, 2001. Olympia, Washington. Pages 133-257.

List of Interviews

Interview numbers (in parentheses) were assigned to each interview.

Beechie, Tim — Northwest Fisheries Science Center, NMFS, Seattle, WA.
(I12) 6/7/01 Phone

Bernath, Steve — Policy Analyst, Water Quality, Washington Dept. of Ecology, Olympia, WA. Was with WA DNR Forest Practices during negotiations.
(I14) 6/8/01 Phone

Bilby, Robert E. — Western Timberlands Research, Weyerhaeuser Company (was with NMFS 7/98 to 9/00).
(I8) 6/6/01 Phone
(I9) 6/6/01 Voice mail

Boyd, Wade — VP Timber, Longview Fibre, Longview, WA.
(I10) 6/6/01 Phone
(I6) 6/5/01 Phone

Heide, Peter. — Director of Forest Management, Washington Forest Protection Association.
(I15) 6/14/01 Phone

Hunter, Mark — Research Scientist, Washington Dept. of Fish and Wildlife, Olympia, WA.
(I3) 6/1/01 Phone
(I7) 6/5/01 Phone

Hyink, Dave — Weyerhaeuser Company, Federal Way, Washington
(I4) 6/4/01 Phone

Martin, Fred — Biometrician, Lands and Resources Division, Washington DNR, Olympia, WA.
(I2) 6/1/01 Phone

Oliver, Chadwick — College of Forest Resources, University of Washington.
(I5) 6/4/01 Phone

Pavel, Joseph — Habitat Policy Analyst, Northwest Indian Fisheries Commission, Olympia, WA.
(I11) 6/6/01 Phone

Welty, Jeffrey J. Biometric Support Engineer, Weyerhaeuser, Federal Way, WA.
(I16) 7/3/01 Phone
(I13) 6/7/01 Phone (75% recorded) (I1) 5/25/01 In-person

Appendix A

Minimum Tree per Acre Analysis by Welty (W1)

FOREST & FISH DESIRED FUTURE CONDITION THINNING GUIDELINES

MINIMUM TREE PER ACRE ANALYSIS

In order to determine appropriate minimum post harvest tree per acre requirements, the following strategy is employed:

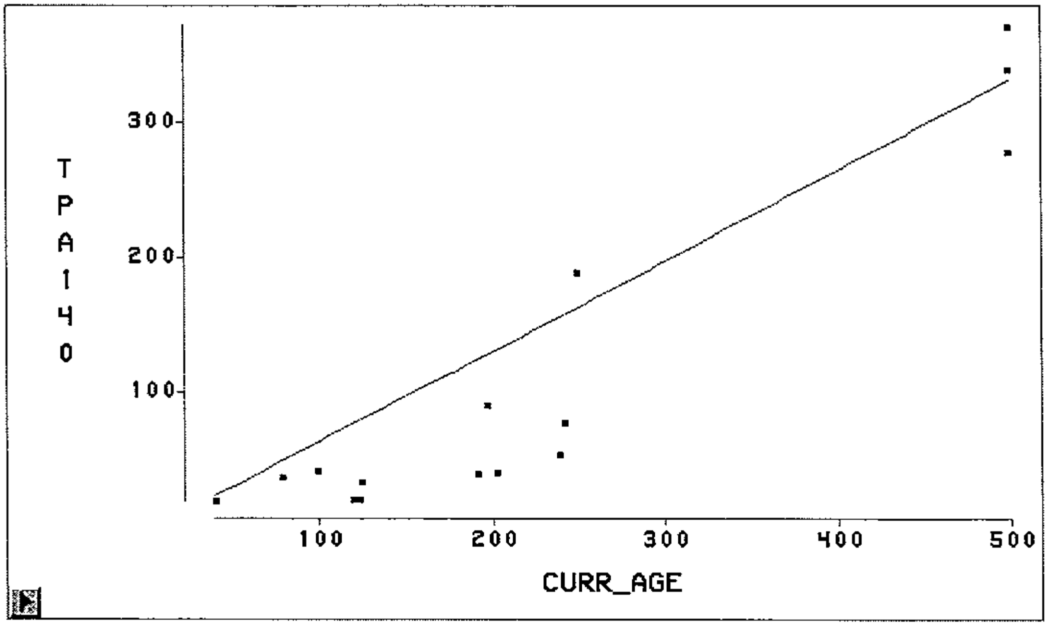
1) Determine the range of TPA levels that might reasonable exist at total age 140.
2) From that range, determine the *minimum* TPA that would exist at age 140, that would fully occupy the site (MTPA)
3) Determine the expected rate of windthrow for the riparian buffer.
4) Using the windthrow rate, compute the post harvest TPA level required so that after windthrow MTPA trees will be standing and grow into the total age 140 condition.

Step 1. Determine the range of TPA levels that might reasonable exist at total age 140.

DATASOURCE	DBH LIMIT	AGES	# PLOTS
Tappeiner, et. al.	19.7"	50-400	40+ (10 sites)
Munger	14"	50-250	598 (summarized as 4 age groups)
Paeiline Railroad Company Cruise	unknown	500 (estimated)	192 (summarizes as 3 Sections)

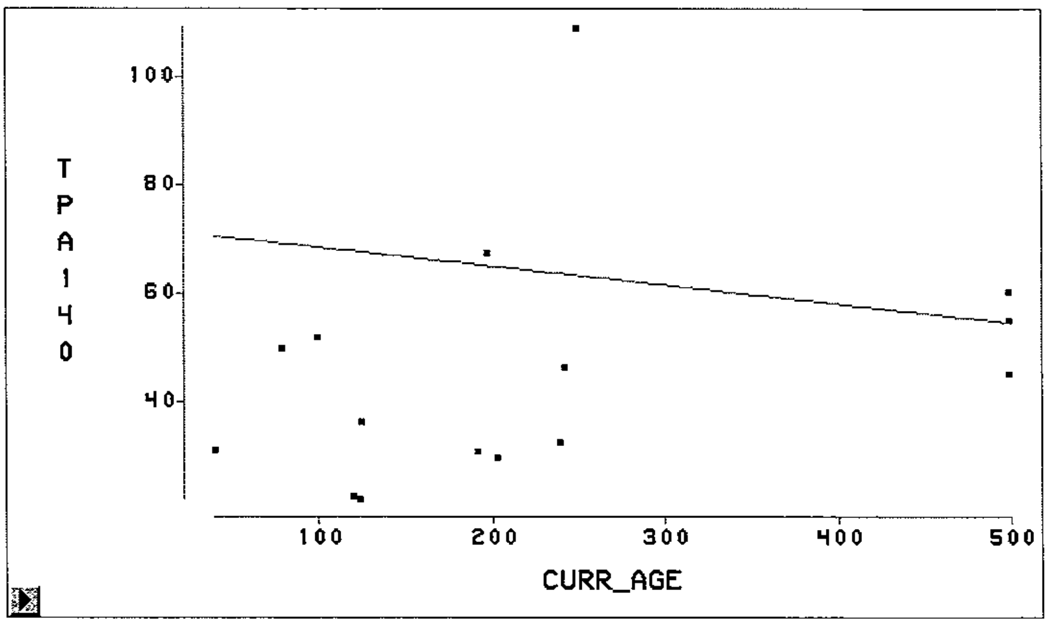
The challenge is, given a TPA and AGE, how do we estimate the TPA at age 140 for the given plot? 2 methods were investigated. (All analyses weight data by the plotsize). First, a simple linear regression was fit:
Tpa = 81.0638 – 0.1438 * age, Rsquare = 0.8934
This is the least reliable way of estimating tpa at age 140, given the wide range of stand conditions represented by the data, and mortality being a nonlinear function. It does, however, give us a crude estimate of the tpa at age 140, which from this method is 60.9
Another, more robust analysis method, is to iteratively apply differing mortality rates to the plots, and then project the plot tpa forward in time (if the plot data is less than 140 years) with the equation TPA140 = current_tpa * (1.0-mortality_rate)**(140-plot_age), or project the plot tpa backward in time with the equation TPA140 = current_tpa / ((1.0-mortality_rate)**(140-plot_age)).
Each mortality rate will produce a dataset of TPA140 and age, which can be plotted and statistically analyzed. Analyzing these datasets gives us a way of evaluating which mortality rate is appropriate for the entire dataset. For example too high a mortality rate will back-project unreasonably high TPA140 levels from stands greater than 140 years, and unreasonably low TPA levels from stands less than 140 years. Statistically, we are looking for a mortality rate where the slope of the line of TPA140 vs current age is 0.0. The plot for a mortality rate of 1.0% looks like:

Model Equation						
TPA140	=	-	5.2204	+	0.6733	CURR_AGE



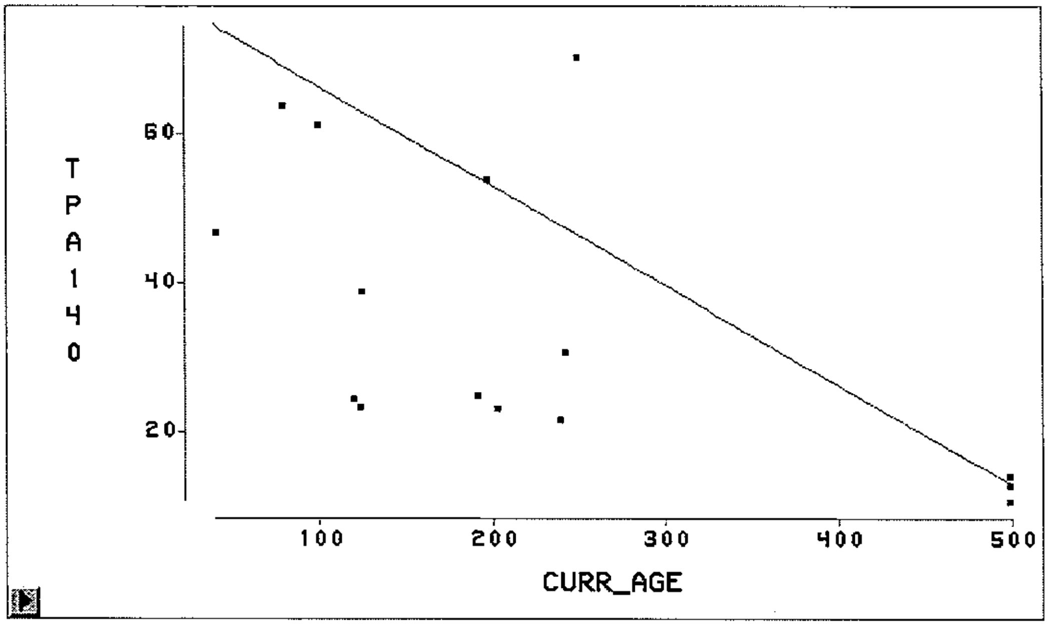
A rate of 0.5% looks like:

Model Equation					
TPA140	=	72.0432	-	0.0347	CURR_AGE



and a rate of 0.1% looks like:

Model Equation					
TPA140	=	79.8826	-	0.1335	CURR_AGE



Further fine tuning of mortality rates indicates the appropriate mortality rate for this data is 0.56%. McCardle (USFS Bulletin 201), shows a mortality rate of 0.5% (net mortality + ingrowth) from age 150 to age 160, for trees larger than 12 inches, separately confirming that 0.56% is a reasonable estimate to use for mortality.
Information from the projected TPA140 using a mortality rate of 0.56% is as follows:

Mean: 67.9
Std Dev: 159.4
Std error of the Mean: 3.5
Minimum: 21.9
First quartile: 31.2
Median: 48.5
Third quartile: 69.1
Maximum: 116.8

The mean of 67.9 is not very different from the estimate of 60.9 provided by the linear regression approach.

Step 2. Determine the minimum TPA LEVEL given the range of TPA at total age 140
The number we will use must, by definition be less than the mean, since we are not interested in the average tpa found in older unmanaged stands, but the minimum acceptable tpa found in the range of TPA140's expressed in those stands. First quartile estimate of 31.2, and median of 48.5 will be evaluated.

OTHER RELAVENT INFORMATION
(Site occupancy of residual trees, as indicated by crown closure using Arney's crown diameter equation.)
Running ORGANON on Site Class III, with the following inputs produces

1) TPA at age 50 of 48.5, and a 15 inch average tree size shows crown closure by age 70.
2) TPA at age 50 of 31.2, and a 15 inch average tree size shows crown closure by age 100.

These results show the trees will have occupied the site well before age 140. A 15 inch average tree size is conservative, as we will only encounter the minimum tree per acre limit where there is good conifer stocking in the core zone, and subsequently the largest trees must be left on the site in the inner zone.
Step 3. Determine the average windthrow rates
Grizzel et. al. summarized windthrow rates from the literature. The average windthrow rate for all sites is 14.2%
Step 4. Compute TPA leave requirements based on target TPA at age 140 and windthrow.

AGE 140 TARGET TPA	LEAVE TPA (=TARGET/(1.0-WINDTHROW/100)
31.2	36.3
48.5	56.5

These numbers need 1 more adjustment to account for post-thinning mortality due to sun-scald, etc.

Appendix B

Desired Future Conditions –
Projecting Stand Conditions, by Welty (W2)

DESIRED FUTURE CONDITIONS

PROJECTING STAND CONDITIONS

Step 1
Creation of base data

The ORGANON growth model (Hann, et. al, 1995) is run to create initial sets of data to for further statistical regression. The stands are assumed to be unthinned and unfertilized. Individual data tables are created for unique site class, percent hardwood, and total stand age. Site classes are standard Douglas-fir site classes (I through V). Percent hardwood is 50%,40%,30%,20%,10% and 0% (basal area basis). Total stand ages modeled are 35, 55,75,95,115 and 135.

Thus, we have a uniqe data table created by ORGANON model predictions for the following base conditions:

SITE CLASS	PERCENT HARDWOOD	TOTAL AGE
I	50	35
I	50	55
I	50	75
I	50	95
I	50	115
I	50	135
I	40	35
I	40	55
I	40	75
I	40	95
I	40	115
I	40	135
I	30	35
I	30	55
I	30	75
I	30	95
I	30	115
I	30	135
I	20	35
I	20	55
I	20	75
I	20	95
I	20	115
I	20	135
I	10	35
I	10	55
I	10	75
I	10	95
I	10	115
I	10	135
I	0	35
I	0	55
I	0	75
I	0	95
I	0	115
I	0	135
Etc. for sites III, IV and V	…	…

The data table for each of these unique cases is created by using (post harvest) trees per acre (tpa) of 50,60,100,150,200,250 and 300, and for each of those trees per acre using (post harvest) basal area (ba) of 50,60,100,150,200 and 250 square feet per acre. A stand table is created with those initial conditions, supplied as data to ORGANON, and grown until total age 140, where the basal area of conifer and trees per acre of conifer are saved for further analysis. (Note that ORGANON is told to remove hardwood trees per acre equally over 10 year periods until no hardwood remains alive at total age 100 to simulate red alder senescence.)

Step 2
Creation of regression coefficients

Once all the data tables are created, each table is individually fit to the following equation:

Equation 1: Min_tpa = b0 + a * tpa + b * tpa/ba + c * ba

Where:

Min_tpa = tpa * DFC/ba140
Tpa = post_harvest tpa
Ba = post_harvest ba
DFC = Desired Future Condition Basal Area target
Ba140 = basal area at age 140 as projected by ORGANON for a unique starting condition.
B0,a,b,c are regression coefficients

The variable of interest to predict (dependent variable in statistical language), is actually ba140, but the formulation of equation (1) was based on other criteria, it fits exceedingly well , with R-Squares on the order of 0.99 and better, so equation (1) is treated as an algebraic identity in use. The errors of prediction of ba140 have been examined and are extremely small, usually less than 1 percent. This is well within the range of error prediction of ORGANON itself, and is not cause for concern.

Now, for each table there exists equation (1) and a unique set of coefficients that can be used to reproduce the table for nearly any starting tpa and ba.

There are constraints applied to the use of the equation when applied to stocking lower than 50 tpa or basal area lower than 50 sq ft per acre, or percent hardwood greater than 50 percent per acre. If the stocking or basal area is less than 50 (tpa or sq ft), then the tpa or ba supplied to the equation is 50, and a simple discount factor is applied to the resulting prediction. For example if the starting tpa was 40, then the ba140 would be predicted with a tpa of 50, then adjusted down by a factor of 40.0/50.0 . Similar logic applies for percent hardwood greater than 50.

The purpose of these constraints are twofold, first to prevent extrapolation errors from equation (1), and to prevent ORGANON itself from being used in stand types (of percent hardwood), where very little if any data was used in the construction of ORGANON. These constraints are conservative, but not unrealistic.

Step 3

Prediction of basal area at age 140 using equations and coefficient tables

Interpolation/extrapolation :

Most stands don't fall exactly on the age and percent hardwood midpoints used in buiding the tables, therefore it is necessary to interpolate between ba140 prediction midpoints. A 2 dimensional simple linear interpolation is applied. This involves finding the 4 nearest midpoint pairs of (age, %hw) to the requested age and percent hardwood, and applying a double linear interpolation. For stands whose age is less than 35 or greater than 135, this will be an extrapolation.

Again, remember the equation is not used to directly predict stands with percent hardwoods greater than 50 percent, the highest percent hardwood supplied to the equation is 50, and discount factors used to estimate ba140 for higher than 50 percent. This also applies to stands with less than 50 square feet of basal area or less than 50 trees per acre.

Appendix 1
Creating Stand Tables for ORGANON

1) Given the tpa,ba, and age of a species of a stand component to project compute dq = sqrt(ba/tpa/0.005454154).

2) For Douglas-fir compute the height of the dominant trees via king's site curve and the site class midpoint (ie. 65, 85,105,125 and 145 feet at index age). Use king's 1966 years to breast height eqn to determine years to breast height given a site index. (For western hemlock use Wiley 1978 for site index and years to breast height)

3) Create the stocking table (tpa by dbh) by using a normal curve, and a CV of dbh of 30%, iteratively search (classic root finding problem) for the avgdbh that, given the following, when you sum of the trees in the stock table give the required ba and tpa.
   - dmin = avgdbh - 2*stddev (make sure dmin is >= 0.5)
   - dmax = avgdbh + 2.*stddev (make sure dmax is <= 99.0)
   - apply normal distribution, get tpa_hat = sum of all tree factors, compute f = tpa/tpa_hat. multiply all tree factors by f, then get ba_hat = sum of ba in all dbh classes.
   - When ba_hat - ba is within tolerance, you're done, else iterate again,

4) Assign heights to the dbh classes using:
   - Curtis's height vs dbh eqn (ht = 4.5 + a*(exp(b/dbh**c)),
   - the stocking table,
   - B = 5.911978, C = -0.2874065 (coefs from SMV version of ORGANON (Hanus,Marshall,Hann 1999, ht-dbh of 6 species...)

It's then just some algebra to find the "a" needed to insure that average ht of the largest 80 tpa in the stock table equals the dominant height from the site curve.

For hardwood we just assign a value of 0.0 to all the heights and let ORGANON assign the heights. All hardwood use species code 312 (bigleaf maple), though the intent is that hardwood is really alder, which will be dealt with in the growth projection process.

Appendix 2
Projecting Stand Tables with ORGANON

The only real trick here is that "hardwood", in terms of DFC, must be senesced by total age 100 (i.e. it's really alder and ORGANON doesn't yet senesce alder. So, we have to thin out the hardwood in several steps to simulate mortality.

This is the logic (note that ORGANON is run in growth intervals of 5 years)

If the total age of the stand is 55 reduce the trees per acre of hardwood by %20
If the total age of the stand is 65 reduce the trees per acre of hardwood by %25
If the total age of the stand is 75 reduce the trees per acre of hardwood by %33
If the total age of the stand is 85 reduce the trees per acre of hardwood by %50
If the total age of the stand is 95 remove all remaining hardwood

Appendix C

PARMDF2.DAT

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AGE	SITE	% HDWD	b0	a	b	c
35	1	0	0.911780	0.680757	2.786172	-0.034823
35	1	1	6.108847	0.677354	1.731325	-0.043096
35	1	2	14.719207	0.664315	0.570694	-0.049553
35	1	3	24.207393	0.685458	-3.062479	-0.058910
35	1	4	31.482993	0.744997	-7.161183	-0.066152
35	1	5	38.048855	0.842315	-12.157496	-0.071643
35	2	0	1.144449	0.662864	3.119887	-0.037048
35	2	1	6.874481	0.659859	1.925666	-0.048035
35	2	2	15.893281	0.648126	0.661435	-0.059507
35	2	3	26.090798	0.644498	-0.975283	-0.066627
35	2	4	34.809526	0.693908	-4.668497	-0.078712
35	2	5	41.887079	0.772101	-8.078292	-0.083570
35	3	0	2.581247	0.631466	3.205627	-0.043774
35	3	1	8.877852	0.627897	2.053849	-0.057001
35	3	2	18.127673	0.615524	1.091391	-0.070516
35	3	3	27.945995	0.604717	0.894095	-0.078171
35	3	4	35.562802	0.640229	-0.466572	-0.086094
35	3	5	42.754761	0.706830	-2.072127	-0.092423
35	4	0	4.563355	0.557967	3.155683	-0.049874
35	4	1	11.235140	0.551702	2.352904	-0.064800
35	4	2	19.671979	0.535382	2.461217	-0.076848
35	4	3	27.133189	0.517033	4.405885	-0.079415
35	4	4	33.284816	0.536721	5.443848	-0.084003
35	4	5	40.149447	0.588609	5.728808	-0.092379
35	5	0	8.375624	0.481438	3.299137	-0.061005
35	5	1	14.489803	0.466853	3.814849	-0.072329
35	5	2	20.587611	0.440526	6.303371	-0.075611
35	5	3	25.264356	0.417228	10.297217	-0.071502
35	5	4	30.407658	0.426060	12.927917	-0.075178
35	5	5	37.146486	0.462537	14.896656	-0.085806
55	1	0	12.752839	0.717509	1.975132	-0.075205
55	1	1	22.607275	0.707158	2.323199	-0.090597
55	1	2	30.923495	0.743527	0.467457	-0.105327
55	1	3	38.094676	0.811905	-2.488690	-0.119414
55	1	4	44.422037	0.921996	-6.398065	-0.133930
55	1	5	44.554167	1.131722	-13.782296	-0.148222
55	2	0	13.674565	0.700505	1.741999	-0.082011
55	2	1	24.947423	0.685111	1.372187	-0.102320
55	2	2	35.608796	0.679970	2.043015	-0.116002
55	2	3	43.044510	0.725679	0.650808	-0.128594
55	2	4	49.289383	0.794815	-0.364216	-0.134478
55	2	5	50.831870	0.918036	-1.090519	-0.130681
55	3	0	16.395494	0.664774	1.804658	-0.093175
55	3	1	26.641958	0.647073	2.135447	-0.110617
55	3	2	36.838650	0.629462	4.304899	-0.121139
55	3	3	43.711145	0.661198	4.744408	-0.130466
55	3	4	50.757254	0.716878	5.092139	-0.139248
55	3	5	54.728570	0.806980	6.900399	-0.137641
55	4	0	18.047839	0.579333	2.833819	-0.096361
55	4	1	26.056661	0.556869	4.735305	-0.106361
55	4	2	34.043857	0.536907	8.079496	-0.112419
55	4	3	40.313772	0.561056	9.638973	-0.122158
55	4	4	46.901564	0.610361	10.861262	-0.133262
55	4	5	52.507272	0.684483	13.678886	-0.138622

55	5	0	19.027542	0.480250	6.442822	-0.093323
55	5	1	24.331785	0.454179	10.300425	-0.095653
55	5	2	30.196988	0.438929	14.315932	-0.099664
55	5	3	35.753069	0.458559	16.732997	-0.110375
55	5	4	42.489840	0.502369	18.741084	-0.126720
55	5	5	50.058063	0.566674	22.192838	-0.143335
75	1	0	34.398115	0.762519	1.662859	-0.150493
75	1	1	42.795672	0.805736	-0.783364	-0.168382
75	1	2	50.500822	0.860871	-3.012483	-0.176146
75	1	3	52.289265	0.951904	-4.829899	-0.167763
75	1	4	47.907777	1.106147	-7.873036	-0.148087
75	1	5	44.263151	1.379650	-20.354130	-0.160185
75	2	0	31.683354	0.698100	7.828117	-0.135347
75	2	1	41.016192	0.704511	9.371519	-0.153528
75	2	2	49.561981	0.740268	9.526879	-0.168462
75	2	3	54.910939	0.800814	10.308964	-0.175119
75	2	4	57.199108	0.912723	9.838990	-0.177277
75	2	5	61.122553	1.151592	0.017612	-0.215159
75	3	0	32.942584	0.651456	8.739113	-0.139362
75	3	1	41.783287	0.640373	12.298679	-0.152889
75	3	2	49.961976	0.665210	13.923306	-0.166145
75	3	3	55.220411	0.710616	16.596515	-0.171229
75	3	4	58.161864	0.780407	20.796995	-0.167696
75	3	5	62.223916	0.927266	21.123833	-0.181354
75	4	0	30.937063	0.554303	11.509943	-0.128574
75	4	1	38.417677	0.538847	15.788054	-0.139028
75	4	2	46.325309	0.557271	18.108941	-0.154402
75	4	3	51.854108	0.598795	20.932520	-0.164098
75	4	4	56.860250	0.659189	25.074182	-0.170057
75	4	5	62.797252	0.774506	27.831214	-0.186526
75	5	0	27.155306	0.446846	17.591013	-0.110784
75	5	1	33.501244	0.436187	21.720733	-0.120804
75	5	2	40.598556	0.451116	24.663650	-0.136853
75	5	3	46.712830	0.489785	27.550110	-0.153101
75	5	4	53.270222	0.541932	32.098411	-0.168604
75	5	5	59.442481	0.628446	37.857592	-0.183521
95	1	0	46.502683	0.759777	17.154478	-0.181828
95	1	1	54.433147	0.788031	18.859459	-0.193403
95	1	2	66.421172	0.845161	17.439887	-0.215890
95	1	3	73.333269	0.960289	13.745236	-0.233504
95	1	4	89.623282	1.187227	-1.655590	-0.306578
95	1	5	145.534439	1.569956	-41.820156	-0.537008
95	2	0	54.552659	0.732109	17.724316	-0.226102
95	2	1	59.855415	0.763886	20.065058	-0.233532
95	2	2	69.542753	0.820197	20.049117	-0.256763
95	2	3	76.533229	0.931365	16.507111	-0.280930
95	2	4	85.918655	1.110137	7.373123	-0.320202
95	2	5	136.095856	1.422213	-24.540007	-0.531748
95	3	0	48.387428	0.631125	26.537868	-0.191889
95	3	1	54.290752	0.655111	29.899898	-0.201664
95	3	2	61.342591	0.699177	32.545012	-0.215098
95	3	3	68.992014	0.798984	30.705892	-0.242778
95	3	4	84.949406	0.988240	18.083288	-0.314194
95	3	5	137.158250	1.284015	-13.497247	-0.528328
95	4	0	42.985707	0.519417	29.817278	-0.166742
95	4	1	49.247389	0.534517	33.874827	-0.179577
95	4	2	56.378497	0.570597	37.251640	-0.195765

95	4	3	60.695270	0.638213	40.043672	-0.206827
95	4	4	73.421914	0.781246	34.262477	-0.260184
95	4	5	119.515874	1.049970	8.445017	-0.455327
95	5	0	35.311164	0.409264	35.609218	-0.135906
95	5	1	41.815138	0.421867	39.588550	-0.152692
95	5	2	48.923729	0.451679	43.443337	-0.172020
95	5	3	53.082923	0.495902	49.103262	-0.181727
95	5	4	62.661133	0.593216	50.156716	-0.218374
95	5	5	99.298478	0.805781	34.713006	-0.373949
115	1	0	68.456012	0.734713	56.545848	-0.287663
115	1	1	73.680917	0.717952	60.606626	-0.300540
115	1	2	80.525833	0.695206	64.895922	-0.313630
115	1	3	80.526007	0.680499	70.830194	-0.310828
115	1	4	80.513526	0.664217	77.326183	-0.305425
115	1	5	79.948521	0.650665	84.500341	-0.299213
115	2	0	68.871228	0.679064	57.371039	-0.282822
115	2	1	73.065876	0.667806	60.979170	-0.295678
115	2	2	77.777798	0.654303	64.931359	-0.309715
115	2	3	77.791156	0.639177	70.645435	-0.308903
115	2	4	77.431340	0.619365	77.340494	-0.305801
115	2	5	76.164866	0.597569	84.751781	-0.298906
115	3	0	62.264299	0.585192	63.843897	-0.251251
115	3	1	66.177410	0.579835	66.546531	-0.264609
115	3	2	70.237206	0.573961	69.316383	-0.277899
115	3	3	70.882631	0.566890	73.346145	-0.280488
115	3	4	71.172468	0.557592	77.894775	-0.281296
115	3	5	70.593059	0.545335	83.152599	-0.278412
115	4	0	50.606102	0.457922	66.483682	-0.199131
115	4	1	52.750760	0.455206	68.634364	-0.206468
115	4	2	55.602916	0.451745	70.752980	-0.215850
115	4	3	55.984188	0.448406	73.601739	-0.217624
115	4	4	56.356949	0.444044	76.656478	-0.219063
115	4	5	56.536877	0.439323	79.851698	-0.219915
115	5	0	39.064559	0.344150	69.173068	-0.152430
115	5	1	40.585669	0.342434	70.408269	-0.157153
115	5	2	42.730600	0.343236	71.268672	-0.164942
115	5	3	43.390405	0.344929	72.436986	-0.168190
115	5	4	44.056819	0.345896	73.687418	-0.170978
115	5	5	44.684261	0.346719	74.928984	-0.173485
135	1	0	38.487802	0.299505	202.848098	-0.164642
135	1	1	38.288085	0.286294	206.238937	-0.160725
135	1	2	39.262732	0.272919	209.278630	-0.160174
135	1	3	37.432844	0.262072	212.886679	-0.152331
135	1	4	36.223766	0.252242	216.281613	-0.147002
135	1	5	35.543356	0.244976	219.407430	-0.145355
135	2	0	37.707518	0.270712	197.245455	-0.159002
135	2	1	37.312954	0.260463	200.312141	-0.156504
135	2	2	37.230969	0.249549	203.322414	-0.154603
135	2	3	35.639125	0.238706	206.708633	-0.147991
135	2	4	34.029787	0.226929	210.171900	-0.140762
135	2	5	32.231622	0.214581	213.670302	-0.132113
135	3	0	33.043866	0.230503	189.315431	-0.136260
135	3	1	32.900736	0.223670	191.634971	-0.135200
135	3	2	33.022224	0.216541	193.894397	-0.134904
135	3	3	31.970212	0.209439	196.436334	-0.130863
135	3	4	30.895054	0.201599	199.054315	-0.126475
135	3	5	29.779697	0.193753	201.647344	-0.121975

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135	4	0	25.012270	0.173573	170.492886	-0.101554
135	4	1	25.197026	0.170565	171.807771	-0.102104
135	4	2	25.582840	0.167392	173.065183	-0.103240
135	4	3	25.097933	0.164130	174.548379	-0.101559
135	4	4	24.657051	0.160561	176.038658	-0.099910
135	4	5	24.144891	0.156899	177.538153	-0.098012
135	5	0	16.981275	0.118737	151.986735	-0.067912
135	5	1	17.470337	0.118971	152.328825	-0.069870
135	5	2	18.099741	0.119392	152.605264	-0.072322
135	5	3	18.181188	0.119822	153.011444	-0.072987
135	5	4	18.304203	0.120103	153.411617	-0.073715
135	5	5	18.380400	0.120203	153.825568	-0.074205